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by

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HUMAN TRANSLATION

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Laser Scribing System for Amorphous Silicon Solar Cells

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Laser Scribing System for Amorphous Silicon Solar Cells[1]

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Abstract: In this paper, we described a laser scribing system for fabrication of a-Si solar cells and its theoretical analysis. The system has been used to scribe the TCO and a-Si films in the production.

Key Words: solar cells, laser scribing

In 1976, American scientists invented amorphous silicon (a-Si) solar cells. A-si possesses excellent photo-electric conductivity. Near 500nm, the photo absorption coefficient of a-Si is one magnitude larger than that of single crystal silicon. It is also suitable for mass production. The conversion efficiency of a-Si solar cell of sizes $1cm^2$ is 11.5%. The conversion coefficient of $100cm^2$ a-si solar cells is 9%.

A simplified composition of an a-Si solar cell is shown in Fig. 1. It consists of substrate (such as glass, ceramics), transparent conducting oxide (TCO such as In-Sn oxide), amorphous silicon (a-Si) layer and metallic film layer (such as Al, Ti). After scribing, the transparent electric conducting layer and metallic layer are top electrode and bottom electrode respectively.

In the past, fabrication of a-Si solar cells usually uses protection film method and light scribing method.

Laser scribing method

The advantages of using laser scribing method (Fig. 2) to fabricate a-Si solar cells are:

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a. There is no need for protection film. Fabrication cost is reduced. The sizes can be as large as 40cm × 120cm.

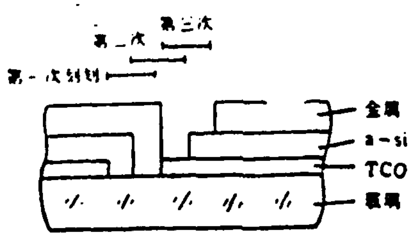

Fig. 1 Cross section of a-Si solar cells. (i) First scribing, (ii) second, (iii) third, (iv) metal, (v) glass.

[1]Received Oct. 16, 1990

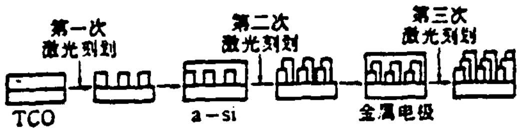

Fig. 2 The laser method of integrated a-Si solar cells. (i) first laser scribing, (ii) second laser scribing, (iii) third laser scribing, (iv) metallic electrode.

b. The scribing line width of the laser is 20-150μm. Hence the effective area can be increased up to 80-94%.

c. Laser scribing production can be automated.

The disadvantages of a-Si solar cell fabrication using laser scribing are:

a. The thickness of laser scribing is less than 1μm film. Furthermore it is difficult to require that no damage be done to other film coating which the film is supported by.

b. Laser scribing anneals the a-Si region at the sides of scribed slit. The local a-Si is converted to multi-crystal silicon, which in turn causes electric leaking current to increase.

c. Laser scribing of large area a-Si is done by moving working parts. Therefore it is time consuming.

Since a-Si solar cells consist of multi-layer films. While scribing one layer of film, one should not damage the other film layers.

1. Theoretical analysis

When a beam of laser shines on a layer of a-Si coated on TCO/glass, the oscillation reflection ratio of the laser, R_a, can be expressed by the thickness of various layers[1]:

Formula (1) here

where, $\delta_j = 4\pi \overset{*}{n_j} d_j \cos\theta_j/\lambda$ $(j = 1,2,3)$, r_j is the reflection index, $\overset{*}{n_i}$ is the complex form of refraction index, d_j is the film thickness, θ_j is the incident angle, ψ_1 is the phase difference, $R_e=|R_a|^2$ is the energy reflection rate.

Fig. 3

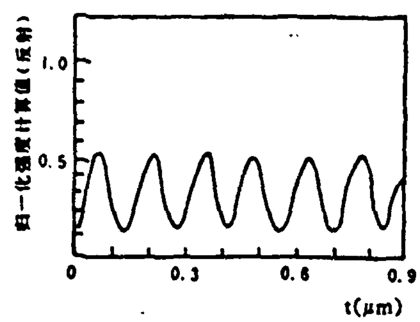

Fig. 3 Reflection intensity and minimum laser power density as functions of film thickness. i) Calculated intensity (reflection)

Computational results obtained by substituting physical values of a-Si film into formula (1) are shown in Fig. 3. The laser beam reflection rate has a periodic relationship with the film thickness variation. This is due to the effect of light interference.

Since metals have high heat conductivity and high reflection index, selective scribing of metallic electrode on the TCO coating is even more difficult. Use heat diffusion equation[2]:

$$\rho c \frac{\partial T}{\partial t} = \frac{k}{c}\left\{\frac{\partial}{\partial r}\left(r\frac{\partial T}{\partial r}\right) + \frac{\partial}{\partial z}\left(r\frac{\partial T}{\partial z}\right)\right\} - \frac{\partial w(r,z,t)}{\partial z} \qquad (2)$$

where ρ is density, c is heat capacitance, T is the temperature, k is heat conductivity, w is the spatial distribution of laser power density. For Al/a-Si/TCO/Glass structure, temperature distribution (computational values) of various laser power density is shown in Fig. 4. We observe from the figure that good selective scribing effect can be obtained for 8.0×10^6 W/cm^2 power density.

2. Scribing method

To avoid difficulty in controlling the depth of laser scribing and the annealing effect, good choice of laser scribing method can simplify the problem.

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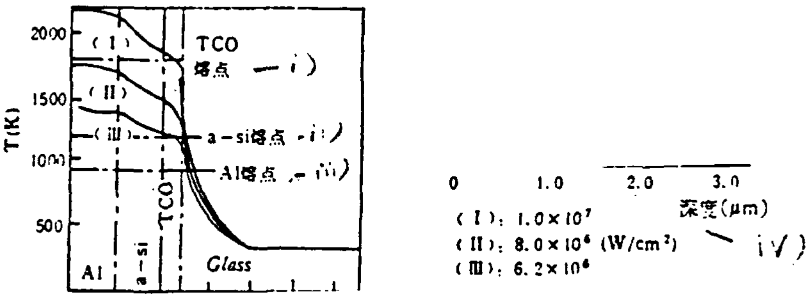

Fig. 4 Temperature distribution of various laser power density (computational values). i) TCO melting point, ii) a-Si melting point, iii) Al melting point, iv) depth.

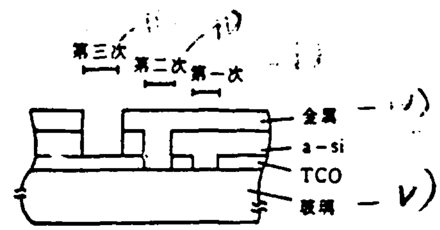

Fig. 5 i) first, ii) second, iii) third, iv) metal, v) glass.

The method shown in Fig. 5 does not require controlling the scribing depth during the second scribing. TCO electrode keeps contact with the metallic electrode through side wall region.

The method in Fig. 6 is similar to that of Fig. 5 except that the third scribing is even better than that of Fig. 5.

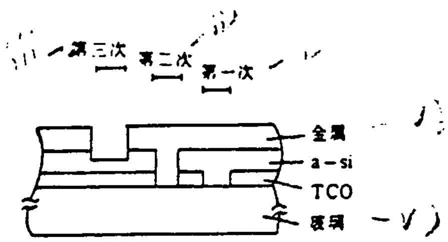

Fig. 6 i) first, ii) second, iii) third, iv) metal, v) glass.

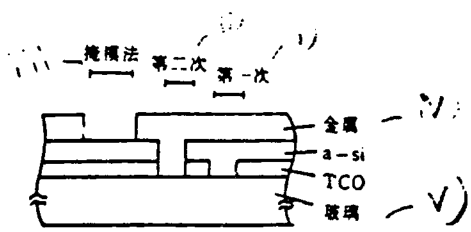

Fig. 7 i) first, ii) second, iii) protective coating method, iv) metal, v) glass.

Fig. 7 shows laser - protective coating hybrid method. The first and second scribing use laser. The third scribing uses protective coating. Like the methods shown in Fig. 5 and Fig. 6, the shortcoming of this method is that the effective area of the solar cell is reduced. Its strength is in increasing productivity. For the methods shown in Fig. 5 and Fig. 6, the third laser scribing anneals a-Si on the edge of the slit and converts it into multi-crystal silicon. In this conversion region, electric leaking current flows between the top electrode and the bottom electrode or between neighboring electrodes. In the structure shown in Fig. 7, on the other hand, the multi-crystal silicon formed in the a-Si layer at the edge of the second slit by second laser scribing can be avoided, because this region will become the contact region between the top electrode and bottom electrode of neighboring two cascading photo cells.

The method we use to fabricate amorphous silicon solar cells is laser-protective coating method.

Laser scribing system for fabrication of a-Si solar cells

The laser system used as scribing light source outputs 1.06μm laser. After passing optical systems of beam widening and focusing, the laser is focused on the body to be scribed which is lying on the surface of the working table. The working table is driven to move by the control system, desired lines are scribed on the film of the body.

The diagram of the entire machine is shown in Fig. 8.

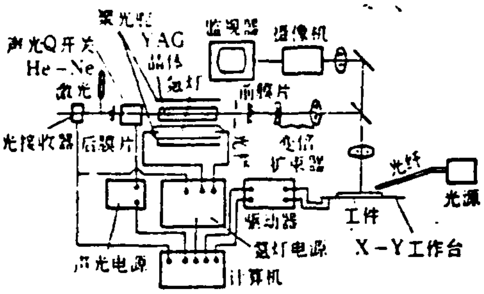

Fig. 8 Diagram of solar cell laser scribing system. i) focusi^ng chamber, ii) monitor, iii) video camera, iv) acoustics-optics Q switch, v) YAG crystal, vi) Kr lamp, vii) front film, viii) magnifying diverging lens, ix) light slit, x) He-Ne laser, xi) light receptor, xii) rear film, xiii) acoustics-optics electric source, xiv) computer, xv) electric source of Kr lamp, xvi) driver, xvii) processing part, xviii) fibre optics, xix) light source, xx) working table.

1. Laser - optics system

(1) Laser system

The laser system includes YAG laser used as scribing source and He-Ne laser used for alignment. Melt quartz acoustics-optics switch used as tuning Q component can turn continuous laser into 1 kHz - 10 kHz impulsive laser. The running frequency of the acoustics-optics driver is 40 MHz and the maximum output power is 30 W.

The continuous power of the YAG laser is 30 W in multi-mode and 2 W in single mode. After acoustics-optics tuning, the single mode peak power of 1 kHz impulsive laser is greater than 10kW, and the half width of the impulse is 200ns.

(2) Diverging, focusing optics system

Diverging, focusing optics system includes diverging magnifying telescope, focusing objective and light splitter - reflector mirror assembly.

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To meet the requirement for line width in different layers in a-Si solar cell scribing, we developed a continuously magnifying diverging telescope. The range of magnification is between 2 - 6 times. Magnifying diverging telescope consists of an eyepiece assembly with variable focal length and a fixed focal length objective. The eyepiece assembly with variable focal length is a typical optics-compensated variable focal length system of simplest structure. As eyepiece moves, the eyepiece assembly changes focal length continuously. Hence the diverging power continuously varies accordingly.

To safeguard scribing quality, severe restriction is placed on the aberration of the focusing objective at $\lambda = 1.06\ \mu m$, especially the dispersion circle on the focal plane. The objective is also used for short distance far center imaging. It has the same rear intersection distance for the white light and $1.06\mu m$ light. Its aberration matches with that of camera objective.

The focal length of this objective is f' = 100mm. Its rear intersection distance is L'=84mm. The adjustment range of the objective is $\Delta L_p = \pm 5mm$.

To meet the demand of system optics, we installed three 45° reflective mirrors throughout the optical system. They are coated according to the various requirement on reflectivity and penetration.

Since the video camera is used not only for monitoring but also for targeting during the scribing of the different layers of the solar cells. The demand on scribing observation of transparent conducting film is much stricter than for the observation of general objects. Hence low illumination RCA-1500 black and white video camera is used. It uses f'=150mm long focal length objective. Its resolution is above 400 line-pair/mm. And it has a high resolution monitor.

For clarity of the line image of different layers during the whole scribing process, low illumination, large angle, reflection, critical illumination method is used. We use quasi monochromatic light, without infrared cold light source to reduce the heat dissipation during fiber optic transmission, which in turn reduces temperature increase in the working area.

2. x-y working table system.

The drive part uses rolling screw assembly, which is driven by a variable current, variable speed servo motor, to transmit motion. It has very high targeting precision and axial rigidity. The transmission efficiency of this method is improved 3-4 times compared with that of sliding screw assembly. Furthermore, there is smaller friction, longer life, and easier maintenance. Software controls and modifies the transmission gap of rolling screw. High precision straight rolling guide is used. Therefore, the working table can move easily and freely on the guide. The movement is stable and without crawling. The performance is very reliable. It is especially suited for high speed movement and micro feeding. The moving part has hardware position limits. In addition, software position limiting is incorporated to provide safety to the costumers.

Servo control drive system includes digital control and servo drive parts.

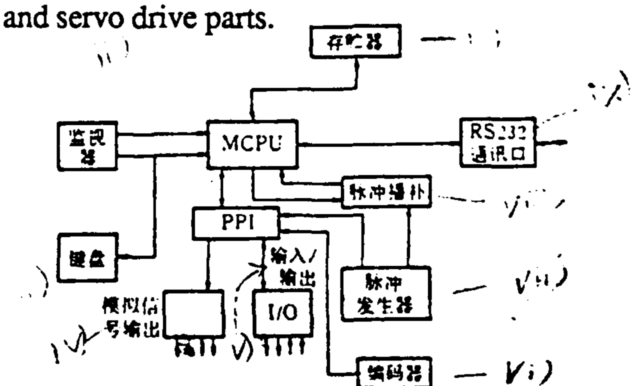

Fig. 9 CNC control flow chart. i) memory, ii) monitor, iii) keyboard, iv) analog signal output, v) input/output, vi) coding unit, vii) impulse generator, viii) impulse amplifier, ix) RS232 communication interface.

Servo control flow chart is shown in Fig. 9.

MTC-IT CNC controller can be programmed from the keyboard on the front panel. It can also be programmed from external devices. The display is used for dialogue between the controller and the operator. Customer can use four different methods to input (record-playback method, teaching method, compiler method, input/output method). When using the input/output method, the program can be transmitted to CNC through external devices (RS232C). The other methods directly input customer processing instructions from CNC front panel. This means that programming can be done both on the site and from other places (programming room). If the programming is done through external devices, ISO code has to be used. A program starts with %. It is followed by instruction number P × × × × × and then by LF. Following that is the N for the first paragraph of the program. At the end of every paragraph and before the N at the start of the next paragraph, a 'LF' linefeed has to be inserted. The whole program must be terminated by "ESC". Each program consists of the following parts: paragraph number N, preparation function, coordinate values, feeding speed, secondary functions (laser control etc.)

Though each program may not need to have all of the above commands, each paragraph must be arranged according to the above order.

Alternating current variable speed servo motor is controlled by AC 200 servo drive unit. It is used to drive AC mouse cage inductive motors. Servo drive combined with linear coding unit, serving as position feedback measuring unit, to provide precise position control. To provide stability of the control system, coaxial speedometer is installed as speed feedback device. In the control loop, position error phase monitoring device provides speed command.

The servo control flow chart is shown in Fig. 10.

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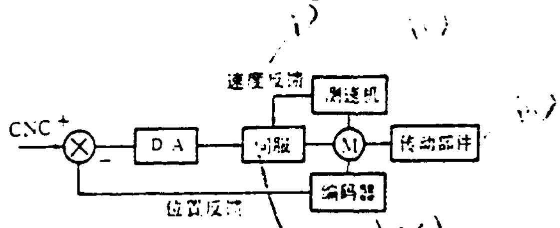

图 10

i) speed feedback, ii) speed measuring device, iii) transmission parts, iv) coding device, v) servo, vi) position feedback.

The whole coordinate working table system can operate automatically. It can also be operated manually. It has good anti-disturbance capability.

Laser scribing experimental results

Using amorphous silicon cell laser scribing machine, controlling laser power density and scribing speed, and through large amount of technological tests on different coating layers for the solar cells, we have produced high efficiency, large size amorphous silicon solar cells[3].

The laser scribing system has reached the following overall technical specifications:

X-Y working table movement range: 400mm × 500mm

Positioning precision: ± 15μm/300mm

linear speed: 150mm/s

scribing width: 100μm (adjustable)

targeting precision: less that half line width.

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[1] M. Born, E. Wolf Principle of Optics (Chinese edition) 1978, p77.

[2] S. Nakano et al., Proc of ICSWE' 85, p11.

[3] Zhong Boqiang et al., Journal of Inorganic Materials, 4, No. 3, 269 (1989) (in Chinese).

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